Airborne Topographic Mapper (ATM) Light Detection and Ranging (LIDAR)
REQUEST FOR INFORMATION (RFI)

Background

The Airborne Topographic Mapper (ATM) LIDAR (Light Detection And Ranging) is a laser-based remote sensing system developed and used by NASA for observing the Earth's topography from manned and unmanned aircraft for a variety of applications including ice sheet mapping, land-based foliage studies, bathymetric investigations, etc. Generally, a complete ATM LIDAR "system" consists of several subcomponents as follows:

1. **<u>LIDAR</u>**: unit that utilizes a laser to accurately measure the distance from the aircraft to the observed surface. Laser types, scanning/optical techniques, photo-detectors and data resolution vary depending upon surface being measured (e.g., ice, foliage, water, etc.), altitude of the aircraft and other variables. Typically, the LIDAR resolves the Z component in the typical XYZ three dimensional space.
2. **<u>Global Positioning System (GPS)</u>**: sub-component that provides latitude, longitude, altitude and time information regarding the position of the instrument in space. Typically, the GPS will resolve the X, Y and time components of the data. (NOTE: NASA science missions may take place at locations that require use of a terrestrial GPS base station)
3. **<u>Inertial Navigation System (INS)/Inertial Measurement Unit (IMU)</u>**: sub-component that provides necessary information relative to the attitude of the aircraft/instrument (pitch, roll and yaw).
4. **<u>Flight Computer/Data Recorder</u>**: sub-component that collects data from the LIDAR, GPS and IMU and formats/organizes the data in time for download and analysis after a flight/mission. The flight computer may also organize the data for delivery to a communications device for line-of-sight (LOS) or over-the-horizon (OTH) transmission. Conversely, the flight computer may be substituted with a data recorder/controller unit.

For the purpose of this RFI, NASA is investigating opportunities to use advanced ATM LIDAR technologies on a variety of Unmanned Aerial Systems (UASs) ranging in size from small vehicle platforms (less than 50 pounds net payload-carrying capability) to large platforms (multi-hundreds of pounds in net payload). With the former, the challenge is to minimize the mass and volume of the ATM LIDAR (including all its sub-components) to be able to be conveniently and effectively deployed on small UASs. The targeted object is a composite system that has less than 40 lbs total mass, less than one cubic foot in volume and uses less that 500W of power. Compromises on overall system accuracy MAY be considered in favor of miniaturization of the overall unit. For the larger UAS platform, mass/volume/power is not as much of a concern. Therefore, only the highest accuracy solutions will be considered.

Given the diverse objectives between the two targeted platforms, this RFI is divided into two sections – the first to address a small UAS solution and secondly, the larger UAS solution. The offeror may address any or all of the four (4) subcomponent items: LIDAR, GPS, INS/IMU, flight computer. However, NASA is most interested in an integrated system that is comprised of all the necessary components required to formulate a fully-functional ATM LIDAR.

SMALL UAS ATM LIDAR ("mini-ATM LIDAR")

NASA currently uses a manned aircraft-based ATM LIDAR system operating out of its Wallops Flight Facility (WFF) in Virginia. The system commonly flies aboard the NASA P3-B, the DC-8, and twin-otter (DHC-6) aircraft. The system has been used for surveys around the world for scientific measurement of sea ice, verification of satellite radar and laser altimeters, and measurement of sea-surface elevation and ocean wave characteristics.

The ATM LIDAR typically operates in the aircraft at altitudes between 400m-800m (1312’ to 2624’) above the terrain, and measures topography to an accuracy of <10 to 20 cm by analyzing measurements derived from the GPS , INS/IMU and LIDAR and applying custom post-processing analytical methods. Since the current system flies on larger manned aircraft, it is not optimized for mass, volume and power consumption.

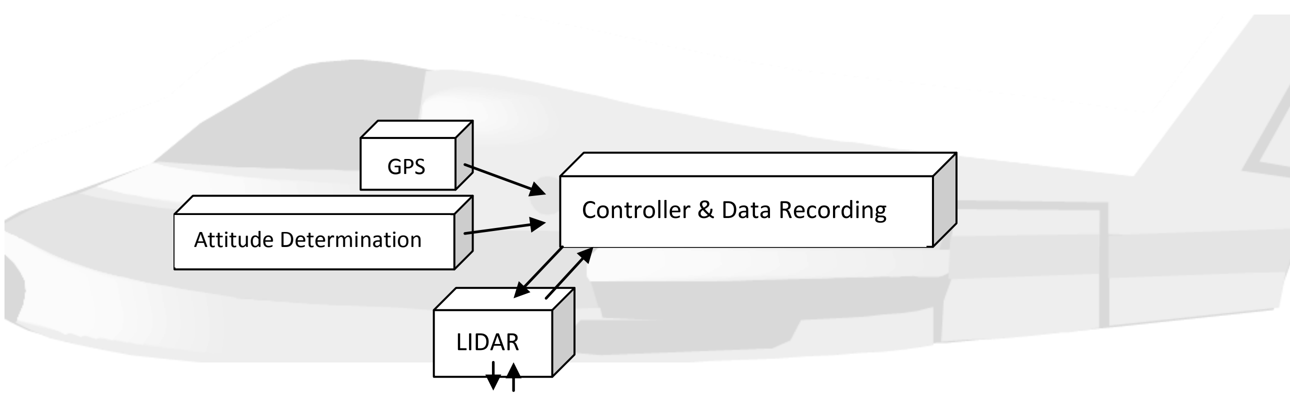
NASA’s objective is to miniaturize its ATM LIDAR (e.g., develop a “mini ATM LIDAR”) from this large manned aircraft-based platform (~350 to 400 lbs) to one of a size and weight that can be installed and flown on a small-to-medium-class UAS. The instrument technical parameters, especially operational resolutions and accuracies of the various subcomponents, must achieve comparable results to the current manned aircraft ATM LIDAR.

Technology Definition

The ATM uses LIDAR technology, which is a laser based remote sensing instrument that determines the range of a distant target. The term “Laser Radar” is sometime used to describe the technology due to similarity in analogy with radar, although the actual technology is quite different than that of radar. The prevalent method to determine distance to an object or surface is to use laser pulses, by measuring the time delay between transmission of a pulse and detection of the reflected signal.

The ATM used by NASA is in family of Airborne Laser System (ALS). The ALS includes the following components to be able to be functional as a scientific instrument.

1. Laser-based instrument (emitter, reflector, ranging/collector unit)
2. Attitude determination system. Typically a gyro-based Inertial Navigation System (INS) is used for this component.
3. Position Determination System. Global Positioning System (GPS) is typically used for this purpose.
4. Controller and Date Recording Hardware to control the instrument and record data



Requirement Development

In order to discuss the mini-ATM requirements, the requirements are broken into three different categories <u>based on the mini-ATM project goal</u>. The requirement categories are as follows, and majority of the requirements are derived based on the current ATM capability.

1. Can be flown with small to midsize UAV (**Platform Driven Requirements**)
2. Can generate equivalent science data to the current ATM system (**Science Driven Requirements**)
3. Operational/Environmental considerations (**Mission Driven Requirements**)

Platform Driven Requirement

The following requirements are driven from the project requirements to fly the mini-ATM system on a small-midsize UAV. Currently, there is no industry standard definition of UAV classes that directly correlates to payload size and weight. Therefore, the requirements are driven by project level estimate and compared against Viking-300 (L-3 Unmanned Systems) for sanity check.

	Current Capability (ATM-T2 & T3)	Mini-ATM Requirement
Weight Requirement		
LIDAR Instrument	50-100 lbs	**< 25 lbs**
Total Weight	350-400 lbs	**< 40 lbs**
Volume Requirement		
Total Volume	LIDAR+Transceiver+Optics + Instrument Rack	**27,000 cm^3 (0.95 ft^3)***
Power Requirement		
LIDAR Power	> 460 W	**< 70 W****
Total Payload Power		**< 350 W**
Computer Requirement		
Autonomous operation	No	**Yes**
Remote commanding	No	**Yes**
Over-the-Horizon Communication	No	**Optional. Comments/input is welcomed.**
Processing speed		**Maintain accuracy between 40-60 kts cruise speed. Comments/input is welcomed**

*. The listed amount is for total volume. The system needs to be able to be broken down to various components to mount to various UAV compartments not co-located.

**. The listed number is for general power budget. The system requirement is on the total power which is limited by the power plant of the UAV.

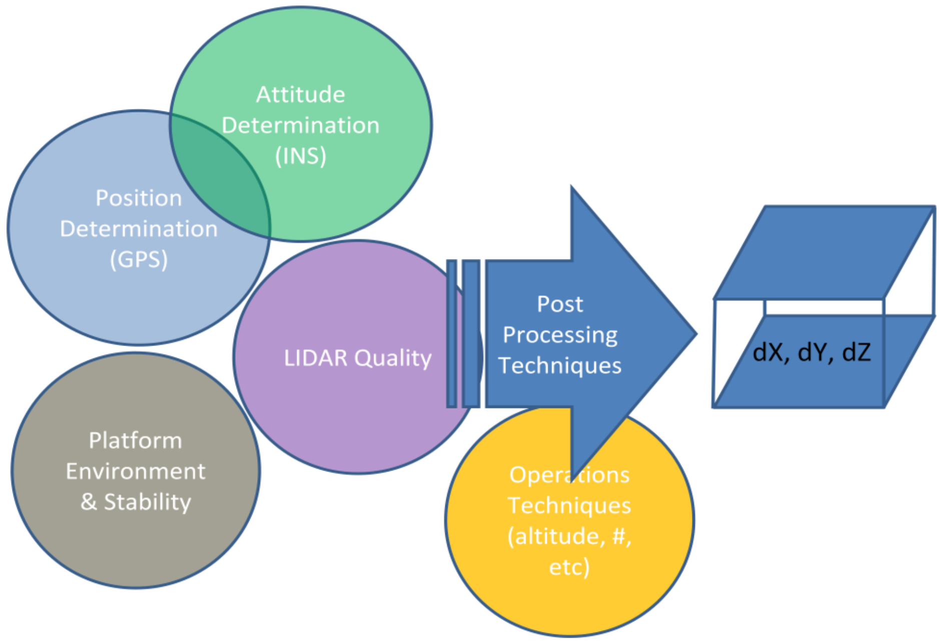
Science Driven Requirement

As illustrated in the Technical Description section, there are 4 major components to ALS. Each of these components is source of error for the final product. In addition to these components, there are errors that arise due to the system configuration, such as platform stability, environment and geometric configuration of the components. Following list summarizes the various error sources, along with an illustration of various components as they influence the final science product.

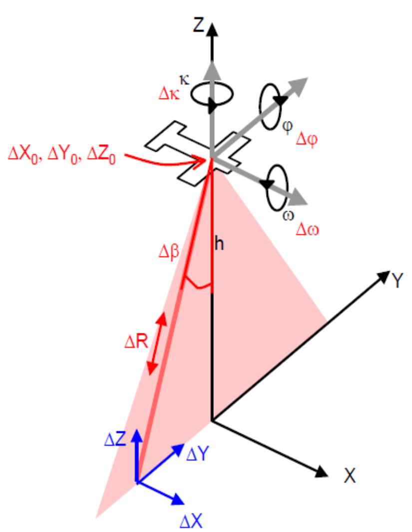
- Laser measurement (range, angle: electronics aging & drift)
- DGPS (receiver, satellite constellation, ground reference constellation)
- INS (receiver: frequency, drift)
- Offset / alignment between GPS, INS, laser scanner
- Dynamic bend of IMU / scanner mounting plate

• Time synchronization and interpolation (GPS: 1-10/s, INS 200/s, turbulent flight)
• Transformation to local coordinate system
• Basic geometric configuration

Source: [Brenner, 2006]



Since the components such as platform environment, post processing techniques and operations techniques are independent to the instrument, the variable components are narrowed down to the accuracy of position determination, attitude determination and the LIDAR quality. The chart below illustrates the error budget for the error caused by position determination –GPS- (ΔX_0, ΔY_0, ΔZ_0), attitude determination –INS- ($\Delta\kappa$,$\Delta\varphi$,$\Delta\omega$), and LIDAR quality ($\Delta\beta$,ΔR).



Error budget (geometry)

error in \ due to	β	Δω	Δφ	Δκ	Δβ	ΔR	ΔX_0	ΔY_0	ΔZ_0	Total	Total @h=1000
ΔX	0			0						22.4	53.0
	15	0	20.9	7.5	0	0	8	0	0	23.6	56.2
	30			16.1						27.6	66.6
ΔY	0					0				26.4	63.5
	15	20.9	0	0	14	1.3	0	8	0	26.4	63.5
	30					2.5				26.5	63.6
ΔZ	0	0			0	5				9.4	9.4
	15	5.6	0	0	4	5	0	0	8	11.7	19.1
	30	12.1			8	4				17.0	37.3

Assumptions: h = 400 m (except last col. h = 1000 m), $\omega = \varphi = \kappa = 0$, $\Delta\omega = \Delta\varphi = 0.03°$, $\Delta\kappa = 0.04°$, $\Delta\beta = 0.02°$, ΔR = 5 cm, $\Delta X_0 = \Delta Y_0 = \Delta Z_0$ = 8 cm

cm: 0 | 0-5 | 5-10 | 10-15 | 15+

Source: [Baltsavias, 1999a]
Claus Brenner
ikg

International Summer School "Digital Recording and 3D Modeling", Aghios Nikolaos, Crete, Greece, 24-29 April 2006

Source: [Baltsavias, 1999a]

As the figure above illustrates, each of the 8 parameters influences the errors in varying weight. In this document, instead of specifying the requirement for each of the parameters, it is appropriate to set the requirement on the final error on the target, that is, the ΔX, ΔY and ΔZ. The current NASA ATM system produces product that is as good as 10 cm to 50 cm depending on the angular location (β). The same accuracy is required for the Mini-ATM system. There is no requirement for the laser wavelength for this RFI, however, description on the proposed wavelength is welcomed along with pros and cons as it applies to ice mapping application.

	Current Standard	Mini-ATM Requirement
Horizontal & vertical Accuracy	Less than 50 cm Lat & lon error at max β and ~10 cm error at β=0	**Average error of less than35 cm Lat & Lon**
Depth Accuracy	+/-15cm	**+/-15cm**
Scan Swath		**Minimum of 100m at 400m flight**
Wavelength		**Comments/input is welcomed**

As a reference, following table shows the error tolerance of each component for the current ATM system. These numbers are just for reference and are not requirement for the mini-ATM.

GPS		
	Position Accuracy	x,y = +/- 2 cm *
		z = +/- 5 cm *
INS		
	Angular accuracy	R,P = 0.005 deg * 0.02 deg**
		Y = 0.015 deg* 0.02 deg**
	Position Accuracy	x,y = +/- 2 cm *
		z = +/- 5 cm *
Instrument		
	Accuracy	2-3 cm detector

*. Based on APPLANIX POS LV 610
**. Based on LITTON LN-100G WITH GPS

Mission Driven Requirements

Applications of ALS includes but not limited to baseline topographic mapping, long term ice mapping, long term coastal erosion mapping, storm impact studies and coral reef studies. The operational requirements for the mini-ATM will vary depending on the applications and operation environment. However, since the current ATM is used heavily on ice mapping, the mini-ATM, at minimum, should satisfy the operational requirement for the mission. Following is the list of the operational environment. These mission driven requirements are considered low priority requirements since the instrument mission may change in the future. Therefore, if the proposed system does not meet these parameters, any input and comments regarding the proposed parameters will be welcomed.

Operations Temperature	-20 ^{o}C to 60 ^{o}C
Operational Altitude	Ceiling of 1,000m (3,280 ft)
Duty Cycle	80 % of flight over terrain
Other	Humidity resistant/ability to resist in-cloud flight

Summary

The intent of the small UAV section of this RFI is to solicit the best ideas from industry and academia to solve the volume/weight/quality constraint to mount a LIDAR on to a small UAV. The response can be on any or all four components of the mini-ATM system. That is, the information may be on an integrated system, or just simply on the standalone LASER instrument. If the response is on a single component rather than an integrated solution, please comment on the anticipated challenges for integration. NASA understands that some of the requirement parameters may be a tradeoff between other parameters, and any discussion will be welcomed.
The following table summarizes the requirements discussed.

Platform Driven Requirement	
Weight Requirement	
LIDAR Instrument	< 25 lbs
Total Weight	< 40 lbs
Volume Requirement	
Total Volume	27,000 cm^3 (0.95 ft^3). Needs to ability to break down to various components for placement.
Power Requirement	
LIDAR Power	< 70 W. Reference only. The requirement is on the total payload power.
Total Payload Power	< 350 W
Comm Requirement	
Autonomous commanding	Yes
Remote commanding	Yes
Processing Speed	Able to maintain the Science requirement at cruise speed of 40-60kts
Science Driven Requirement	
Horizontal & Vertical Accuracy	Average error of less than35cm on Lat & Lon
Depth Accuracy	+/-15cm
Scan Swath	Minimum of 100m at 400m altitude
Mission Driven Requirements	
Operations Temperature	-20 ^{o}C to 60 ^{o}C
Operational Altitude	Ceiling of 1,000m (3,280 ft)
Duty Cycle	80 % of flight over terrain
Other	Humidity resistant/ability to resist in-cloud flight

LARGE UAS ATM LIDAR

The NASA Earth Science Division is looking for solutions to extending, enhancing and maximizing Operation IceBridge altimetry data collection through the use of NASA's current unmanned aerial vehicles; the Global Hawk, the MQ-9 Predator called Ikhana, and/or the Sierra.

The minimum requirements which all offerors must meet include:

1. Measuring surface elevations for grounded ice and ice shelves to an uncertainty of 10 cm over 1km x 1km areas and for slopes up to 3 degrees.
2. Measuring surface elevations for sea ice and ocean surface such that freeboard can be estimated to an uncertainty of 5 cm at 500m length scales.

The intent of the RFI is to solicit the best ideas from industry and academia to solve the data collection requirements of Operation IceBridge. Offerors should feel free to propose solutions that meet all or some of the requirements and further, solutions do not have to be compatible between platforms. The intent of this RFI is to in no way constrain the creativity of the offerors to meet the stated requirements through any and all technical means available.

Other platforms or creative solutions may also be proposed at the discretion of the offeror. Currently NASA operates two systems on manned platforms to collect this information: the Airborne Topographical Mapper (ATM) and the Land Vegetation and Ice Sensor (LVIS).

Operation IceBridge Background:

IceBridge is a NASA airborne mission making altimetry measurements to extend the record of change in the Earth's cryosphere started by ICESat in 2003. These measurements showed that 1) the sea ice cover in the Arctic is thinning, 2) ice loss is occurring from throughout the outlet glaciers of Greenland and Antarctica, and 3) also offered insight into the dynamic processes that control the flow of glaciers into the ocean. In addition to altimetry, IceBridge is making other key measurements relevant to improving our understanding of the Earth's cryosphere, especially radar sounding of the ice, snow, and bed and performing calibration-validation work for ESA's recently launched CryoSat 2. The IceBridge mission began operation in 2009 and will continue through the launch of ICESat-2, currently estimated for 2015, to include on-orbit calibration and validation. Also see the following websites below for further information on Operation Icebridge.

Reference

Hydrospheric and Biospheric Sciences Lab webpage: http://atm.wff.nasa.gov/
USGS Center for LIDAR Information Coordination and Knowledge: http://lidar.cr.usgs.gov
http://www.nasa.gov/mission_pages/icebridge/
http://nsidc.org/index.html